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4 TRIALS AGAINST  
CONQUEROR TANKS  
WITH  
ADDITIONAL BALLISTIC PROTECTION  
PART 2  
THE USE OF LARGE HOLLOW-CHARGE WARHEADS

INVENTORY 1971

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**RESEARCH DIVISION REPORT**

ON

**TRIALS AGAINST CONQUEROR TANKS**

**WITH ADDITIONAL BALLISTIC PROTECTION**

**PART 2**

**THE USE OF LARGE HOLLOW-CHARGE WARHEADS**

PASSED:

*W. H. Coulthard*  
(W. H. Coulthard)  
Deputy Director  
(Research)

APPROVED:

*A. E. Masters*  
(A. E. Masters)  
Director

F. V. R. D. E. (Ascot 1160),  
Chobham Lane, Chertsey.  
M. 1058  
3.7.57

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ABSTRACT

The results of static trials of American "Dart" (T.42) hollow-charge warheads fired against a fully stowed up-armoured Conqueror with spaced armour protection indicated that, in these conditions:-

(i) the penetrative performance of "Dart" was extremely marginal, and (ii) when the armour was penetrated the "Dart" kill capabilities were associated with ammunition fires and crew lethality rather than with mechanical damage.

A single experimental "Malkara" hollow-charge warhead was also fired; this produced an effective kill.

The results suggest that a "Dart" type of warhead with the substitution of a copper cone might form a very effective G.W. warhead with a total weight not exceeding 25 pounds.

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TRIALS AGAINST CONQUEROR TANKS  
WITH ADDITIONAL BALLISTIC PROTECTION

General Note on this Series of Trials

These trials, to assess the comparative lethality of various anti-tank warheads, particularly those suitable for guided weapons, are an extension of earlier trials against Centurion 3 tanks; the targets are now Conqueror tanks, with spaced armour and an up-armoured glacis plate, to simulate representative future heavy tanks. Several trials will be undertaken and each will be reported separately.

In assessing "KILL" damage in the trials it should be noted that the War Office definition of a "KILL" is being revised and will now differ from that quoted in the earlier Centurion report. The proposed revised definition (from the unapproved draft of the 3rd revision of W.O.P.S.1) is:-

"Damage to a tank constitutes a "KILL":-

"(a) Either:-

if the main armament is put out of action, either because the crew have been rendered incapable of operating it, or because the armament or its associated equipment has been so damaged as to render it inoperative.

"(b) Or:-

if the tank is immobilised.

**NOTE:** Projectiles used in tank weapons must be capable of inflicting both types of damage as defined above; but a single round need not produce both effects at the same time."

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ACKNOWLEDGEMENTS

Whilst this trial, initiated by the Attack of Tanks Working Party, was planned and co-ordinated by the Research Trials Group, F.V.R.D.E., the actual work was carried out jointly by representatives from several of the Ministry's Establishments, and their assistance is gratefully acknowledged.

Facilities for the trial were very efficiently provided by C.D.E.E., Porton, and they undertook those physiological assessments of crew damage which required the use of animals. C.S.E.E., Farnborough, were responsible for the other aspects of this assessment and they also provided the instrumented dummies. All the records, obtained by Instrumentation Department, R.A.E., were interpreted by C.S.E.E. The "Dart" and "Malkara" rounds were examined, fuzed and initiated by A.R.D.E., Fort Halstead. Finally, acknowledgement is made to the U.S. War Department for arranging the supply of "Dart" warheads.

1. INTRODUCTION

This trial (Part 2 of the series) was concerned primarily with assessing the heavy tank "KILL" capabilities of American "Dart" (T.42) G.W. warheads; these are hollow-charge heads, 7.0 inches (178 m.m.) external diameter, with conical aluminium liners. In addition, a single experimental "Malkara" G.W. hollow-charge warhead, 7.78 inches (198 m.m.) external diameter with a hemispherical copper liner, was tested. The two warheads are illustrated in figure 1.

The Conqueror used as a target was up-armoured and fitted with spaced armour; it was substantially identical to the vehicle used in Part 1 of the series. Similar points of strike were also used in the present trial.

2. ARRANGEMENTS OF THE TRIAL

The trial was carried out at C.D.E.E., Porton, between 4.9.56 and 14.9.56.

2.1 Arrangements for Damage Assessment

Earlier trials with hollow-charge warheads had suggested that crew damage would be a very important factor in assessing "KILL" capabilities. A joint programme was therefore planned to obtain data on the following aspects within the crew compartments:-

- (i) Accelerations experienced by instrumented articulated dummies;
  - (ii) Areas of fragment damage;
  - (iii) Blast pressures
  - (iv) Thermal effects (burns)
  - (v) Light intensities (blinding effects)
- } caused largely by vaporific afterburning of the aluminium cone inside the crew compartments.

An attempt has been made to assess all these effects in terms of probable crew damage and to correlate the assessment with the actual results obtained by placing rabbits in the crew positions.

In addition the usual assessment of structural damage was carried out after each round.

2.2 General Arrangements

2.2.1 Target Details

The target was a Conqueror 1 tank, rebuilt from prototype components by R.O.F., Dalmuir, with the glacis plate increased to 150 m.m. by five welded strips of 20 m.m. applique armour and with 14 m.m. burster plates protecting the glacis and turret (figure 2). This additional armour, detailed in Appendix 1, was identical with that used in Part 1 of this trial, except that the gun shield and nose plate protection were omitted.

The vehicle was fully stowed internally, with H.E.S., A.P.D.S. rounds and empty cartridge cases. Articulated instrumented dummies and live rabbits were located in the crew members' positions.

The special instrumentation arrangements are described in Appendix 2.

2.2.2 Details of the Rounds

Ten "Dart" warheads were supplied for the trial, and on the basis of radiographs (figures 3, 4) the best five rounds were selected. The A.R.D.E. report on these five states:

"All show defects of one sort or another, e.g., transverse and longitudinal lesions, porosity and bad filling at the base of the cone. Probably Number 3 is the best of the five\* and Number 5 the worst, showing as it does bad contact on the walls, porosity (at YY) and discontinuity (at XX); this last fault is probably the most serious."

The rounds were supported against selected points (figure 5) by rope slings and were all fired statically. The ballistic nose of each "Dart" warhead was sawn off at a distance of about 3 inches from the tip (to simulate crushing); the stand-off of each round was thus about  $8\frac{1}{2}$  inches, measured from the burster plate (when used), otherwise from the main armour.

It was intended that all the rounds should be fired through spaced armour (as used in the previous Conqueror trial) but the spaced armour was omitted in later firings when it became apparent that this combination was near the penetration limit of the round.

The single "Malkara" hollow-charge round had no ballistic nose. It was similarly supported (figure 5) at a stand-off distance of 12 inches from the main armour; spaced armour was omitted.

The position at which each round was fired is shown in Table 1 (page 3).

3. RESULTS

Figure 6 (general view) shows the vehicle after completion of the trial, with annotated positions of five of the six rounds.

Detailed results are contained in Appendix 2, under the headings:-

- Part 1 Accelerations experienced by the dummies.
- 2 Areas of fragment damage.
- 3 Blast pressures.
- 4 Thermal effects (burns).
- 5 Light intensity (blinding effects).
- 6 Vehicle damage.
- 7 Effects on rabbits placed in crew positions.

These results are summarised below.

3.1 Performance of the Rounds (Figures 6, 7, 8)

3.1.1 Penetration

The results, which include one failure (Round No. 2) to penetrate 11 inches of armour, suggest that the penetrative performance of the "Dart" warhead, even when fired statically, is extremely marginal for use against heavy tanks. This view has also been expressed by B.R.L., Aberdeen, after plate performance tests. The results indicate that spaced armour may produce some degradation in hollow charge penetration; this effect has been observed on other trials.

The penetration of the single "Malkara" round was quite satisfactory for the relatively favourable conditions (static detonation, long stand-off and no spaced armour) under which it was fired.

3.1.2 External Damage

No serious external damage was caused by the "Dart" rounds; the "Malkara" round produced more external damage, and also, around the jet hole, a large area of characteristic hollow-charge pitting (figure 6), which was sufficient to prevent elevation of the gun by burring the mantlet (KILL damage). This pitting was noticeably absent in the "Dart" rounds (which have no metal case). The use of a metal case undoubtedly produces more secondary damage and should also improve penetration (according to B.R.L. reports) but it increases the warhead weight appreciably; e.g., the "Dart" round (with ballistic cap) weighed 23 pounds; the experimental "Malkara" round (without ballistic cap) weighed 52 pounds.

\* This round was the only failure when fired; it failed to penetrate through a burster plate and 11 inches of armour.

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Table 1

Details of Rounds Fired Against Conqueror

Round No.	Radiograph No.	Position on Tank	Spaced Armour	Stand-off Along Axis of Jet To Spaced Armour	To Main Armour	Main Armour Thickness Along Axis of Jet	Notes
No. 1 (Dart)	2	Front left hand side of turret; azimuth angle 0°.	Yes.	8.5 inches	14.5 inches	9.8 inches	{ Similar to turret strike position in previous trial.
No. 2 (Dart)	3	Front left hand side of turret; azimuth angle 0°.	Yes.	8.5 inches	17.5 inches	11.0 inches	{ Similar to hull strike position in previous trial (but spaced armour omitted).
No. 3 (Dart)	4	Left hand side of glacis plate; azimuth angle 0°.	No.	-	8.5 inches	11.8 inches	{ Position chosen to enable jet to penetrate into turret crew area.
No. 4 (Dart)	5	Front lower left hand skirt plate; azimuth angle 30°.	Skirting plate acts as spaced armour.	8.5 inches	60.5 inches	4.0 inches	{ Azimuth angle introduced to avoid interference with previous jet holes.
No. 5 (Dart)	6	Front left hand side of turret; azimuth angle 30°.	No.	-	8.5 inches	11.0 inches	{
No. 6 (Malkara)	-	Front left hand side of turret; azimuth angle 0°.	No.	-	12.0 inches	10.0 inches	{

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3.1.3 Internal Damage

It is probably a reasonable summary of the internal structural and component damage to say that after five "Dart" rounds (four penetrating) there was no serious damage, and that structurally the tank was still mobile and fightable. There is, however, one important qualification; on three of the four penetrations cartridge cases were damaged and a major (KILL) fire would almost certainly have resulted with live ammunition (figure 8). On a fully-stowed vehicle this form of damage is very likely to occur with conventional rounds (the Conqueror front ammunition stowage being particularly vulnerable) but, it should be noted, it is much less likely with suitably-stowed bagged-charge rounds, such as are likely to be adopted on future British tanks.

The single "Malkara" round produced much more extensive damage within the turret, sufficient to class as a KILL; in addition the jet penetrated and immobilised the main engine (again KILL damage).

3.2 Crew Damage

In terms of crew damage there is for "Dart" a roughly conical lethal zone (with a cone angle of about 30 degrees) centred around the jet path; the depth of the cone is determined by the material encountered, but in general it extends well into the crew compartment. The lethality is due both to fragment concentrations and to thermal effects.

Outside this zone, only slight crew damage (caused by isolated fragments or 1st degree burning) may be expected; no crew damage should result from the accelerations, flash is unlikely to impair crew vision and blast (although sufficient to force off the closed turret hatches) is not considered to produce anything more serious than possible damage to eardrums. It may be observed that of 31 rabbits used during the trial, 26 (outside the lethal cone) survived; the 5 deaths were all caused by fragments.

For "Malkara" (based on a single round) the crew effects appear to be similar but generally rather more severe, with the exception of the thermal effect which is reduced.

4. CONCLUSIONS

The results of this small sample of firings against a single up-armoured Conqueror suggest that:-

4.1 The penetrative performance of "Dart" against heavy tanks is extremely marginal;

4.2 under these conditions, "Dart" does not cause extensive mechanical vehicle damage either externally or internally; it relies for its kill capabilities mainly on:-

(a) Ammunition fires. The incidence of these could be high for conventionally-stowed ammunition but much less for suitably stowed bagged charges.

(b) Crew lethality (due to fragments and burns) within a cone of about 30 degrees; outside this cone crew should not be seriously incapacitated. It seems extremely unlikely that more than two crew members would be killed by a single round.

4.3 It is difficult to draw definite conclusions from the single "Malkara" round (or comparisons, since it was a much heavier round). This round does, however, indicate the increased scale of damage which might be expected from increasing the overmatch of the round in relation to the armour.

4.4 The results are in agreement with those of an earlier A.R.D.E. report (D2 Technical Note No. 19/54) "that the overmatch obtained from a copper liner is a far more serious hazard to the tank than any vaporific effects likely to be obtained from using aluminium".

4.5 The results also suggest the important possibility of producing a very effective anti-tank G.W. warhead with a weight of about 25 pounds, by using the "Dart" design with the substitution of a conical copper liner.

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APPENDIX 1

DETAILS OF SPACED ARMOUR PROTECTION

1. The spaced armour shown in figures 2 and 5 consisted of assemblies of 14 m.m. I.T.100 armour plates with mild steel tubular spacers 1.875" O.Dia. x 10 S.W.G. welded to them at a nominal pitch of 6". The lengths of the spacers varied with the positions occupied by the assemblies. For the spaced armour on the turret the tubes were cut to suit the contour of the main armour and were from 4" to 8" long. The spacers on the glacis plate assembly were 5.75" long.

2. To facilitate replacement of the spaced armour when damaged, the armour was made up in sections weighing approximately 1 cwt. Each section was provided with four steel lugs which were bolted to corresponding lugs welded on the main armour.

3. The weight of additional armour fitted to the vehicle for this trial totalled 2,420 lb., made up as follows:-

	Lb.
Spaced armour including fixtures	
on turret	1,020
on glacis	600
20 m.m. applique armour on glacis	800
	<hr/>
	2,420

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APPENDIX 2

DETAILED ASSESSMENTS OF RESULTS

Sheet 1

PART 1  
ACCELERATIONS OF DUMMY CREW  
by M. A. Elwood, C.S.E.E.

Position of Dummy Crew

Two R.A.E. instrumented dummies were placed in the vehicle for rounds 2 to 6 inclusive. One was seated in the gunner's position, with back lightly in contact with the back rest, feet on the turret floor, arms loose at the sides, and head loosely restrained, allowing a movement of 2 or 3 inches back from the sight browpad. The other was seated in the driver's seat with full support at the back, and the head loosely restrained, allowing 5 to 6 inches movement in the fore and aft direction.

Internal accelerometers were mounted in the heads and trunks of both dummies, and horizontal and vertical measurements were taken at each site.

General Nature of Results

The first 0.03 sec. of most of the traces is characterised by a high frequency oscillation of about 100 c.p.s. In some cases the peaks are off the recording paper; the maximum recorded accelerations are summarised in the following Table.

Maximum Accelerations (g) Recorded with Time in Sec.  
from Base Line to Peak Bracketed Beneath

Position	Round			
	2	3	4	6
<u>Gunner</u>				
Body Hor.	-	-	6.2 (0.002)	A 12
Body Vert.	2.4 (0.004)	4.1 (0.005)	2.9 (0.002)	15 (0.005)
Head Vert.	-	4.0 (0.005)	5.9 (0.002)	15.5 (0.010)
Head Hor.	4.1 (0.005)	12	4.7 (0.002)	A 21
<u>Driver</u>				
Body Hor.	5.0 (0.006)	8.0 (0.004)	6.6 (0.002)	A 14.5 (0.003)
Body Vert.	3.4 (0.004)	8.8	2.6 (0.002)	3.9 (0.003)
Head Vert.	2.7 (0.005)	4.1 (0.003)	A 15	11 (0.003)
Head Hor.	4.9 (0.004)	8 <sup>#</sup>	7.0 (0.004)	4.6 (0.005)

- Notes: A The accelerations in these cases are at least as high as the figures given, but the actual peaks cannot be measured since the trace moves over the edge of the recording paper.
- \* This maximum did not occur during the initial high frequency phase, but later, probably when the head struck a part of the tank.

This initial phase is followed by more prolonged but lower accelerations, the majority of which are less than 1.5g in either direction. Often these accelerations are continued at 5 to 15 c.p.s., but to progressively lower peaks, for up to 5 cycles. This level of acceleration is found in the normal running of tanks over hard smooth surfaces or during cross-country runs. In the following instances somewhat higher horizontal accelerations were recorded in the body:-

Round 2  
Driver 3.0g lasting 0.06 secs.

Round 3  
Driver 2.0g lasting 0.08 secs.

Round 5  
Driver 2.5g lasting 0.06 secs.

Round 6  
Gunner 3.5g lasting 0.02 secs.

Moderate accelerations to the head, probably occurring when the head came into contact with part of the tank, were found as follows:-

Round 3  
Gunner Vertical 2.5g lasting 0.01 secs.  
Driver Vertical 3.0g lasting 0.015 secs. } Simultaneous  
Driver Horizontal 8.0g lasting 0.015 secs. } Resultant 8.6g.

Round 5  
Gunner Horizontal 2.5g lasting 0.05 secs.

Round 6  
Gunner Horizontal 2.0g lasting 0.1 secs.  
Driver Vertical 3.0g lasting 0.05 secs.  
Driver Horizontal 1.5g lasting 0.02 secs. } Simultaneous  
5.0g lasting 0.02 secs. } Resultant 5.2g.

The calculation of resultants has not been possible in all cases, since horizontal and vertical components are only rarely in phase. Two examples of simultaneous peaks in the dummy driver's head are given above.

The onset of acceleration occurs within 0.005 secs. in all positions in both dummies.

There is evidence, from a comparison of an R.A.E. dummy with human subjects when firing 20 pr. from a Centurion tank, that internal accelerations recorded from a dummy are of the same order as external accelerations recorded from men under the same conditions. The maximum accelerations were in general less than those of the present trial. Human subjects have experienced externally measured head accelerations of 5.0g (horizontal) in 0.005 secs. from base to peak, together with 6.5g (vertical) in 0.005 secs., giving a resultant of 8.2g. These accelerations were produced by frontal blows to the head, and associated with a subjective description of "between uncomfortable and definitely painful". Apart from Round 6 the maximum

Appendix 2

Part 1

Sheet 3

internal accelerations recorded from the head would seem to be of this order. Minor cuts and bruises may occur, particularly from contact with vehicle components. Serious injury seems to be unlikely unless, say, a projectile strikes a man's eye.

During F.V.R.D.E. trials with F.V.4005, accelerations of up to 7g were recorded from the trunk of a dummy, both in the horizontal and vertical directions. These conditions have since been experienced by a fully prepared and braced subject without ill effect. The trunk accelerations in rounds 2 to 5 are of this order, and are well below the maximum of 20g (vertical) experienced in seat ejections. It seems that only minor injury (cuts and bruises) could arise under the conditions obtained in the present trial. Elsewhere it has also been stated that accelerations of up to 7g in 0.002 secs. and lasting 0.01 secs. would not be expected to cause injury. (1)

The accelerations recorded during round 6 are higher than the corresponding measurements of earlier rounds. However, the actual displacements involved would be very small and of the order of 0.05 in. for the initial phase. In the secondary phase the displacements would be larger, but are associated with lower peak accelerations. The greatest movement would be for the horizontal acceleration of 2.0g to the dummy gunner's head quoted above. The head would move about 0.75 in. in this case.

Minor surface cuts and bruises would almost certainly have occurred during round 6 but the extent of the incapacitation of the crew must remain an open question.

As no synchronising signal was used to link the two recorders, the chronological relation of the blast wave and the accelerations cannot be estimated.

Conclusion

The accelerations to dummy crew in the gunner's and driver's positions in this trial are likely to cause minor injury only to a human crew, except in round 6 where accelerations were higher. In this case the actual degree of incapacitation remains an open question.

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APPENDIX 2

DETAILED ASSESSMENTS OF RESULTS

PART 2  
AREAS OF FRAGMENT DAMAGE  
by E. J. Champion, F. V. R. D. E.

Sheet 1

The dispersion zones of jet fragments inside the vehicle as indicated by holes and pitting of witness plates and components are given in the table below and shown diagrammatically in figure 10. Lethal zones are bounded by solid lines and areas of maximum spread by broken lines. The average cone angle of lethal fragment zone from the "Dart" is about  $30^{\circ}$ , while that of the "Malkara" appears to be nearer  $40^{\circ}$ . The striking range of the jet fragments depends upon the degree of obstruction in their path; where components of comparatively thin material only are encountered the fragments will travel to the opposite end of the vehicle. On the other hand components of considerable thickness, such as the gun or mounting, afford excellent protection to any member of the crew shielded by them.

Round No.	Head	Position of Attack	Cone Angles of Fragment Dispersion	
			Estimated Lethal Zone	Max. Spread
1	Dart	Front left side of turret (W/spaced armour).	$30^{\circ}$	$60^{\circ}$
2	"	Front left side of turret (W/spaced armour).  (Failed to perforate armour.)	-	-
3	"	Glacis plate opposite ammunition stowage.	$32^{\circ}$	$50^{\circ}$
4	"	Front lower skirt plate on left side of hull.	$14^{\circ}$	-
5	"	Front left side of turret.	$34^{\circ}$	$60^{\circ}$
6	Malkara	Front left side of turret.	$36^{\circ}$	$90^{\circ}$

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APPENDIX 2

DETAILED ASSESSMENTS OF RESULTS

Sheet 1

PART 3  
BLAST PRESSURES  
by M. A. Elwood, C.S.E.E.

The initial peak blast pressures, given in the following table, are reached in 0.001 to 0.002 seconds. Subsidiary peaks often occurred, probably representing reflected waves.

Peak Blast Pressures lb./sq. in.

	Round No.				
	2	3	4	5	6
<u>Fighting Compartment:-</u>					
Behind Breech:-					
L.H.S.	7.3	13.2	11.6	-	-
R.H.S.	-	4.9	20.4	24.8	-
Gunner's Position:-					
L.H.S.	2.3	11.2	} 13.4	} 19.6	} 22.4
R.H.S.	3.5	16.8			
<u>Driver's Compartment:-</u>					
L.H.S.	-	-	-	-	7.6
R.H.S.	9.7	7.6	21.2	3.1	-

Driver's Compartment

These pressures were probably dependent upon blast entering through episcopic ports as well as from the fighting compartment.

Fighting Compartment

These pressures are lower for round 2 (when the attack failed to penetrate) compared with later rounds.

General

Assuming the methods of recording to be comparable, the blast pressures are all well below the limit of 70 lb./sq. in. estimated by Zuckerman<sup>(5)</sup> as that likely to cause minimum human lung damage. Human ear drums may rupture at these pressures, but the effect varies with the amount of wax present.

Comparison with Animal Injuries

The general level of blast pressure is somewhat higher than that found in attacks of a tank with H.E. and H.E.S.H.<sup>(1)</sup> In the latter trial, where rabbits were used, only one instance of minor lung injury occurred, which was attributable to blast, but about one third of the ear drums were ruptured. The injuries found in the present trial included some moderate and minor lung injury, and the rupture of most eardrums. Therefore the data on blast pressure and on animal injury indicate greater blast injury in the present trial in comparison with that found in the previous trial quoted. Nevertheless, incapacitation of a human crew would not be expected.

There appears to be no consistent relation between variation in blast pressure and the degree of animal injury in the present trial. However, the animals and gauges were not placed in exactly the same positions and were subjected to different degrees of shielding.

Comparison with American Data

The American evaluation of the "Dart" warhead showed the weapon to be very effective against a T26E4 tank.<sup>(6)</sup> Blast pressures of 50 lb./sq. in. in the turret, and 30 lb./sq. in. in the driver's compartment were recorded. Wooden dummies (boxes of  $\frac{3}{4}$ " pine) were thrown against the turret walls by the blast, but also showed fragment penetration. These dummies were therefore placed within the fragment cone, where men are likely to be killed or seriously injured. This tank is less heavily armoured than Conqueror and the increased severity of the effects reflects the increased overmatch of the warhead in these conditions.

Conclusion

The measured blast pressures are unlikely to cause serious injury to crew members of a heavy tank who are outside the lethal zone of the jet.

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APPENDIX 2

DETAILED ASSESSMENTS OF RESULTS

Sheet 1

PART 4  
THERMAL EFFECTS  
by K. H. Spring, F.V.R.D.E.

Injuries from thermal causes might be expected either from radiant heat (thermal radiation) or by convection from hot gases. Before the trial, it was thought that the duration of the flash within the vehicle (after penetration) would be about 0.1 sec. and that radiant heat was likely to be the main factor in causing thermal injuries (since, for example, one can pass a hand quickly through a gas-jet flame without harm). At the trial the measured duration of the light flash, and therefore probably also of the thermal flash, was about 0.15 sec.

Measurements of radiant heat have previously been made in connection with experiments on flame warfare and atomic weapons, but in both these cases the thermal pulses have a duration of 1 sec. or more. It was nevertheless decided to use similar field measuring techniques, but to make calibration and assessment in terms of the much shorter duration.

The radiation detectors used were:-

1. Yellow-green gas detector papers.
2. Brown gas detector papers.
3. "Thermindex" temperature indicating paint, E.102.
4. "Tempilaq" laquer, 45°C.
5. Khaki battledress serge.

Nos. 1 and 2 have for long been known to give colour changes on exposure to radiation densities of the same order as those which cause skin burns. Additional calibrations have been made at Physics Division, C.D.E.E., using exposure times down to 0.1 sec. To increase sensitivity, the backs of some samples were blackened. The following table lists the colour changes produced by various energy densities on the basis of a 0.1-0.2 sec. exposure:-

Green Paper	Brown Paper		
	Normal	Near Blackened	
3 cal. cm. <sup>-2</sup>	Detectable red.	1.5 cal. cm. <sup>-2</sup>	Perceptible red.
5 " "	Bright red.	3 " "	Red.
9 " "	Bubbling, yellow.	4.5 " "	Bright red.
		.5 cal. cm. <sup>-2</sup>	Min. perceptible.
		1.5 " "	Red.

Thus a range of 0.5 to 10 cal. cm.<sup>-2</sup> may be measured.

No. 3, "Thermindex" paint E.102, changes colour permanently after long (10 min.) exposure at 115°C. from pink to violet.

No. 4, "Tempilaq", melts at 45°C. after some seconds at this temperature. In both cases, much higher temperatures corresponding to high energy densities are needed for shorter exposures, and in fact no consistent colour changing or melting was obtained during the trial, so that calibration was not undertaken.

No. 5, khaki serge, on the basis of 1 second exposures has been found (7) to behave as follows:-

1 cal. cm. <sup>-2</sup>	Min. detectable damage.
2 " "	Curling of nap.
5 " "	Light charring.
8 " "	Full charring.
12 " "	Bubbling and destruction.

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For comparison, the energy densities required, for an exposure of a few seconds, to cause various degrees of burning to a human subject are<sup>(8)</sup> as follows:-

0.5-1 cal. cm. <sup>-2</sup>	Acute discomfort.
2-3 " "	1st degree burn - redness of skin.
3-4 " "	2nd degree burn - blistering.
8-10 " "	3rd degree burn - deep burns, eventual scarring.

It is estimated that about 6 cal. cm.<sup>-2</sup> would produce an immediate heat casualty in 50% of cases.

There is some uncertainty regarding the values appropriate to exposure times of about 0.1 sec., but the following table gives an indication of what is expected. The 'paint' referred to in columns 2 and 3 is the yellow-green type of gas-detector paint. This paint on thick paper corresponds to the normal gas detector paper.

Exposure Time	Required Energy Density in cal. cm. <sup>-2</sup>				
	Min. Detectable Colour Change, Paint on Thin Paper	Min. Detectable Damage, Thick Paper	Acute Discomfort	2nd Degree Burn	
100 sec.	8.5	23	9	10	
10 "	1.5	8.5	1.5	2	
1 "	0.5	2.5	0.5	1.5	
0.1 "	0.2	0.5	(0.4)	?	1.5

The figures for 2nd degree burns are those of Lidwell.<sup>(7)</sup> There are some discrepancies between the figures in the preceding tables, because the material has been drawn from several sources. However, taking into account both gas-detector paints and khaki serge, the 'reciprocity failure' with time can be reasonably related to that for human burning. It seems likely that serge, which has a matt and hairy surface, will behave much like skin, especially to a mixture of wide-angle radiation and convection. For times of the order of 0.1 sec. or less there should be little reciprocity failure for skin or the various types of detector, since the normal processes of heat loss do not have time to operate.

The heat doses under discussion would, of course, be received only on the unprotected parts of the body, such as the face. Even so, as a practical criterion, it may be assumed that, for a heat flash of 0.15 sec. duration, 2 cal. cm.<sup>-2</sup> would be sufficient to cause 1st, and probably 2nd, degree burning, resulting in temporary incapacity because of pain and shock. About 5 cal. cm.<sup>-2</sup> would cause more prolonged incapacity.

The five types of heat sensitive material were mounted as small samples on hardboard panels about 2 in. sq., half of each panel being blackened before attaching the samples. All except the serge were covered with a very thin layer of laquer to protect them from the possible chemical action of the products of combustion.<sup>(9)</sup> For each shot about 20 or 30 panels were placed in the tank in positions chosen (and noted) so that subsequent examination would permit the spatial distribution of radiant energy to be obtained. The panels were held in position by strong wire to prevent them being displaced by blast, but even so a number near the axes of the jets were lost or rendered useless for measurement. In a good many cases the panels were covered with a greyish film which was cleaned off to observe the colour changes. It is probable that most of the radiant energy would have reached the panels before the material debris, and this clouding over is therefore not likely to affect the results appreciably. The results are shown in a series of scale diagrams (figure 10) the numbers giving the radiant energy densities in cal. cm.<sup>-2</sup>. For clarity only those panels on which a measurable change was recorded are

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shown. The values along the axis of the jets, where measurable, exceed  $15 \text{ cal. cm.}^{-2}$  and thus are lethal, regardless of blast pressure or material fragment damage. Away from the axis the values gradually tail off to the minimum measurable of about  $1 \text{ cal. cm.}^{-2}$ . The shaded region is that in which immediate (but in the outer zones only temporary) incapacity to remain at duty is likely to occur. In only one case (round 4) does the zone of thermal effects lie outside the zone in which serious injury from fragments is likely. In this particular case the gunner would have been shielded from burning to a large extent by the gun.

Conclusion

It seems clear that, with "Dart" thermal effects are of importance only in the region already rendered lethal or hazardous by fragments. Judging from the single round (No. 6) thermal effects from "Malkara" are smaller and confined to the region of the main cone of fragments.

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DETAILED ASSESSMENTS OF RESULTS

PART 5  
FLASH INTENSITY  
by M. A. Elwood, C.S.E.E.

Sheet 1

A photoelectric cell unit mounted on the right turret wall just below roof level, gave the following peak flash illuminations:-

<u>Round 2</u>	22.8	Lumens/sq. ft.
<u>Round 3</u>	-	} Inadequate filters, records invalid.
<u>Round 4</u>	-	
<u>Round 5</u>	55,500	Lumens/sq. ft.
<u>Round 6</u>	144,000	Lumens/sq. ft.

The duration of all these flashes was about 0.15 secs. Since the human blink reflex is generally estimated as about 0.1 secs.,<sup>(2)</sup> most, if not all, of the flash, or its reflection from internal surfaces, would have been seen by the crew had they been present.

The very low flash value for round 2 may be a measure of the external flash penetrating through sights and episcopes, as the round just failed to penetrate the armour. Rounds 5 and 6 were attacks at comparable sites on the turret, but a larger flash was recorded for round 6.

Average intensities of illumination in closed-down tanks are 10 to 15 lumens/sq. ft. by day, and about 0.01 to 1 lumens/sq. ft. may be expected by night.<sup>(3)</sup> Figures are also given for the recovery time (re-adaptation) to the closed-down day conditions after 5 minutes exposures to daylight of up to 10,000 lumens/sq. ft. Men were able to map-read inside the tanks within 5 secs.

The effects of a flash, as in rounds 5 and 6, would be expected to last 10 to 20 secs. when the eyes of the crew are adapted for 10 to 15 lumens/sq. ft. internal illumination. At night the pupil diameter would be increased above that of a semi-adapted daytime crews (about 4 m.m.s) to 5 or 7 m.m.s depending on the orientation of the lighting with respect to the crew.<sup>(4)</sup> Under the latter conditions temporary blindness (to the dim intensities) would be expected to last a few minutes. No permanent injury would occur.<sup>(2)</sup>

Conclusion

The intensity of the internal flash would cause no injury by day and only loss of dark adaptation at night.

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PART 6  
VEHICLE DAMAGE  
by E. J. Champion, F.V.R.D.E.

Round 1 - "Dart" Attack on Spaced Armour on Front Left Hand Side of Turret

Spaced armour (14 m.m.) holed 1.7" x 2.5"; four spacer tubes removed but assembly still in position. Hole through main armour 2.25" x 2.0" on face, decreasing to 1.6" x 1.7" on inside. Face damage: 4.7" x 5.7". Back damage: 4" x 3". Front stowage bin on left track guard ripped open and section of track guard forced down onto track. Gunner's door and column thrown onto ground on front of tank. Loader's door and column thrown onto turret roof. Commander's door forced up 9 inches and column bent.

Two 120 m.m. H.E.S. shell stowed on turret wall thrown onto floor. 16 gauge steel witness plates across left rear of fighting compartment, 5 ft. from jet hole, holed and displaced. Perspex screen,  $\frac{1}{4}$ " thick, between gunner and gun breech, shattered.

Damage to Fire Control Equipment:- Retaining clips on head of gunner's sight fractured. Perspex window of trunnion tilt indicator shattered. Lower window of commander's reflector pitted slightly. Rangefinder internal adjuster, graticule in upper field inoperative, instrument otherwise in order. All external optical surfaces heavily coated with oxide film but easily cleared.

Round 2 - "Dart" Attack on Spaced Armour on Front Left Hand Side of Turret

Spaced armour holed 2.5" x 2.75" and assembly thrown onto ground. Jet failed to perforate main armour. Penetration 1.8" x 1.8" x 11" deep. Face damage: 3.5" x 5.0". Back damage: cracked bulge 4" x 4" x 0.5" high, main crack 3" long open 0.5". Trunnion cheek and end of mantlet pitted 0.3" deep. Hatch doors loaded with three sandbags on each before attack; driver's door lifted 1.5", gunner's and loader's doors - catches sprung. New clips on head of gunner's sight undamaged. Sight movement relative to muzzle boresight = +2 min. R.2 min. No internal damage found.

Round 3 - "Dart" Attack on Up-armoured Glacis Opposite Ammunition Stowage

20 m.m. applique plate holed 6" x 5", broken in two pieces and blown off. Main armour holed 2.6" x 2.6" on face, decreasing to 2.5" x 2.0" inside. Face damage: 6" x 4". Back damage: 7" x 5" including spall 5" x 3" x 0.75" thick.

Left lifting eye on glacis blown off. Underside of gun barrel pitted 0.06" deep (30" above point of attack). Gunner's door blown onto turret roof. Loader's door blown onto ground 3 ft. forward of tank.

Six empty 120 m.m. cartridge cases stowed under glacis holed. Two amplifier boxes (aluminium alloy) on turret turntable, 5 ft. from point of attack, holed: one 1" dia. hole and two .125" dia. holes; this damage had no effect on the amplifiers. 16 gauge steel witness plates at rear of fighting compartment dished 6" over  $34^{\circ}$  x 22". Three holes 0.06 to 0.5" dia. in engine compartment bulkhead.

Rangefinder readings: mean of five before attack = 709 yds.; after attack = 701 yds. Gunner's sight movement relative to muzzle bore sight = +2 min. R.1 min.

Round 4 - "Dart" Attack on Front Lower Skirt Plate on Left Side of Hull

6 m.m. skirt plate holed and torn over 13" x 5" and blown off. Hull side holed 1.5" x 1". Face damage: 5" x 3". Back damage: 3" x 1.25".

Front suspension bracket casting holed 3.25" x 1.5" and main stiffening web cut through. Inner and outer springs pitted and scored but no coils broken. Top plate of bump stop pulled away from rubber and intermediate plate bent. Rebound bracket torn at site of hole in hull side. Idler wheel hub cap blown off and securing studs sheared. Idler bracket cracked

at the track tensioner boss - crack 2" long. Several track links had small holes and a number of circlips were missing.

Two cartridge cases in ready round bin holed and base of bin damaged. Equipment on turret turntable undamaged.

Round 5 - "Dart" Attack on Front Left Hand Side of Turret (Spaced Armour Omitted)

Turret holed. Hole 3.25" x 3" on face, decreasing to 2.0" x 20". Face damage: 4" x 6". Back damage: 3.5" x 5" including spall 4" x 1.5" x 0.3" thick.

Side of turret pitted 0.12" deep. Centre bin on left track guard ripped open. Gunner's door blown off tank. Loader's door blown onto gunner's hatch. Driver's door lifted to full extent.

16 gauge steel witness plates across rear of turret, 6 ft. 6 in. from jet hole, holed - 10 holes in area 16" x 9". Three cartridge cases holed. M.G. ammunition bin behind point of attack torn open and rounds thrown about turret.

Cover of emergency control unit holed and switch unit damaged. Cable on side of gun mounting leading to loader's safety switch severed. Gun elevation hydraulic system out of action - oil pipe holed. Cable to Molins case ejection gear severed.

Access plate on engine compartment bulkhead holed but engine undamaged. Commander's reflector lower window cracked.

Sights in agreement with muzzle bore sight.

Round 6 - "Malkara" Attack on Front Left Hand Side of Turret (Spaced Armour Omitted)

Turret holed. Hole 2.5" dia. on face, decreasing to 2.25" dia. Face damage: 4" x 8". Back damage: 5.25" x 7.5" including spall 4.5" x 2" x 1" thick. Trunnion cheek and end of mantlet heavily scored (0.5" deep). Gun elevation jammed by burring of mantlet and trunnion cheek.

Vehicle immobilised by damage to front end of engine, viz, wheel case, fuel feed pipe to petrol pumps, revolution counter, electric cables. Power traverse on main turret inoperative but hand traverse in order. Fire control traverse jammed by damage to traverse ring - piece 8" x 2" torn out and teeth damaged over 12" of circumference.

Commander's back rest and seat riddled with small holes. Commander's reflector lower window sheltered.

Control turret switch box casing broken front and back and internal components smashed.

Magslip re-setter unit No. 1 casing fractured across fixing bolt holes. Traverse indicator control smashed. Range setter on gunner's sight damaged by strike on pinion rack.

Ammunition stowage: lids of two ready round cases holed.

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PART 7

EFFECTS ON RABBITS PLACED IN CREW POSITIONS

by M. Ainsworth and G. Wedd, C.D.E.E.

The rabbits were placed in hammocks composed of two layers of garden netting, suspended in dexion frames  $8\frac{1}{2}$ " x 14" x  $16\frac{1}{2}$ ", made of duralmin 1.7 m.m. thick. With one exception mentioned later, two rabbits were placed in each case, one above the other, and the cages were placed in appropriate compartments of the tank as late as possible before the trial.

The rabbits were anaesthetised with urethane, usually within 30 minutes of the trial. After the trial they were collected from the tank and removed to the laboratory within 15 minutes. With exceptions to be mentioned later, they were killed with nembutal and examined immediately.

ROUND 1

Two rabbits each placed in driver's seat, commander's seat, loader's seat and gunlayer's seat.

Results

Driver's Seat

Upper Rabbit - Alive.

No external injury.

Abdomen normal.

Chest. Widespread petechial haemorrhages in all parts of both lungs, confluent in upper part of left lower lobe.

This animal would probably have survived.

Lower Rabbit - Alive

No external or internal injury.

Commander's Seat

Cage - About 20 dents by splinters up to 1 cm. diameter. No perforations.

Upper Rabbit - Dead.

Slight singeing of hair.

Anterior part of lower jaw (about 1.5 cm.) missing. This damage was apparently due to a triangular splinter of 1 cm. sides, which emerged just behind the right orbit, lacerating the lower part of the right temporal lobe on the way.

There was an incised wound about 5 m.m. diameter 3 cm. in front of and 2 cm. below the tip of the last left rib, penetrating the abdominal wall and bruising the surface of the liver. There was also a minute perforation in the anterior wall of the stomach. Otherwise abdominal contents were normal.

Thorax contained a small quantity of blood and there was a clot in the mediastinum resulting from the transection of the inferior vena cava. Both lungs were mottled with haemorrhages, some petechial, some massive, up to 1 cm. long.

Brain. Laceration of lower part of R. temporal lobe. Otherwise normal.

Cause of death - Injury to brain, section of inferior vena cava.

Lower Rabbit - Dead.

Fur singed on head and hind quarters.

Incised wound in middle of right side of chest by a splinter which had fractured 6th rib and then passed through heart and diaphragm and entered stomach.

There was a perforation about 7 m.m. long in the anterior wall of the stomach, corresponding to a similar perforation in the diaphragm. Stomach contents had exuded into abdomen and thorax. Otherwise abdominal contents normal.

Thorax was full of blood and stomach contents. Right auricle and ventricle were partly torn away. There were confluent petechial haemorrhages in the greater part of all lobes of both lungs.

Cause of death - Gross damage to heart.

Loader's Seat

Cage - The framework was constructed of  $1\frac{1}{2}$ " duralumin angle bolted together with  $\frac{1}{2}$ " mild steel bolts and strengthened with  $1/16$ " M.S. corner plates.

The "front" of the cage presented an area of approximately 92 sq." and received 337 missiles, the majority being very small. Estimates of the weights and numbers of missiles are given below; these were based on laboratory shots at a specimen of the duralumin angle:-

<u>Missile Weight</u>	<u>Number of Missiles</u>
< 10 gm.	208
< 0.2 gm.	84
0.2 - 1.0 gm.	36
1.0 - 5.0 gm.	6
> 5.0 gm.	3

The velocities of the smaller missiles were probably below 1,000 ft./sec.

The framework was perforated by 8 missiles:-

One was a large object which sheared the angle and a bracing plate.

Two were probably heavier than 10 gm., and travelling at more than 1,500 ft./sec.

Three of these missiles either perforated twice or perforated and then dented. From the measured lines of fire, the source appeared to be common to the three missiles and was situated 29" to the left of the cage "front", 31" in front of the cage and two or three inches below the top of the cage. Indentations of the metal indicate that this may have been the source of most of the missiles.

After correcting for angle of incidence, the calculated fragment flux at a position corresponding to the "loader's" thorax was:-

<u>Missile Weight</u>	<u>Flux (Fragments sq. ft.)</u>
< 0.2 gm.	790
0.2 - 1.0 gm.	97
1.0 - 5.0 gm.	16
> 5.0 gm.	8

Upper Rabbit - Dead.

Severe charring of fur and skin. In the clipped area (thorax and abdomen) the remains of the fur had disappeared and the skin was superficially charred. Sharp shadows cast by the netting were seen on the skin.

There was a comminuted fracture of the right humerus.

There were several incised wounds:-

1. Between scapulae. 3 m.m. long through skin.

2. On right side 3 cm. behind 1. 1 cm. long through skin and superficial muscle.

3. 3 cm. long from tip of last right rib downwards on abdomen.

Through skin and superficial muscle. Embedded in this wound was a splinter 5 m.m. square.

4. Right ankle. 1 cm. long into joint.

5. 2 cm. medial to right glenoid. Penetrating into thorax and lacerating thymus and upper lobe of right lung.

Abdomen. There was a superficial rupture of the right lobe of the liver. It was in the form of a cross and extended about 2.5 cm. in both directions. There was a haemorrhage in the wall of the caecum about 5 m.m. in diameter.

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Thorax contained about 20 ml. of blood clot. The upper lobe of the right lung was lacerated and all lobes of both lungs were covered with petechial haemorrhages which were confluent in places.

Cause of death - Multiple injuries. Haemothorax.

Lower Rabbit - Dead.

Fur singed.

Face. Frontal and parietal bones destroyed by missiles. Brain and tongue exposed.

There was an incised wound 4 cm. long extending backwards from the angle of the left scapula. Through skin and superficial fascia.

Abdomen. Stomach congested with a few petechial haemorrhages on the surface. Appendix intensely congested. Otherwise abdomen normal.

Thorax. Left lung - massive haemorrhage occupying most of lower lobe. Upper lobe contained several small haemorrhages. Right lung - massive haemorrhage in middle lobe. Smaller haemorrhages in upper and lower lobes.

Cause of death - Pulmonary haemorrhage. Damage to brain.

Gunlayer's Seat

Upper Rabbit - Alive.

No external injury.

Abdomen. A single petechial haemorrhage on the anterior surface of the spleen. Otherwise normal.

Thorax. Both lower lobes showed "rib markings" in the form of linear haemorrhages about 2 m.m. wide. Elsewhere there were numerous but not confluent petechial haemorrhages.

Brain substance appeared normal but there was a small amount of ante-mortum clot at the base.

The degree of lung damage would have made ultimate recovery improbable.

Lower Rabbit - Alive.

Slight singeing of fur of right shoulder and thigh and left foot.

Abdomen normal.

Thorax. Numerous petechial haemorrhages on all lobes of both lungs, becoming almost confluent towards the roots.

This animal might have survived.

ROUND 2

No rabbits were used for this trial.

ROUND 3

Two rabbits were placed in each of the four crew positions. After the trial the rabbits were taken to the laboratory and killed and examined on the following day.

Results

Commander's Seat

Upper Rabbit - Alive.

No external injuries.

Abdomen normal.

Thorax. R. lung slightly congested. Area of collapse at lateral tip of upper lobe. 4 small haemorrhages up to 5 m.m. in diameter in lower lobe. L. lung - numerous petechial haemorrhages over most of lower lobe. Collapse of lateral tips of upper and lower lobes.

Ears. Both drums ruptured.

This animal should have survived.

Lower Rabbit - Alive.

No external injury.

Abdomen normal.

Thorax. Numerous petechial haemorrhages in thymus. Lungs. Numerous petechial haemorrhages all over both, becoming confluent in places on the right.

Ears. Drums could not be examined on account of bilateral chronic suppurative otitis media (C.S.O.M.). (The middle ear full of thick pus and drum, if any, bearing no relation to the normal.)

Should have survived.

Driver's Seat

Upper Rabbit - Alive.

Severe singeing all over body.

Abdomen. Slight congestion of small intestine.

Thorax. A few small haemorrhages in thymus. Right lung congested, particularly lower lobe. Numerous petechial haemorrhages. Left lung - "rib markings" represented by 4 linear haemorrhages about 4 m.m. wide; two each in upper lobe and upper part of lower lobe. Massive haemorrhage in medial part of lower lobe.

Ears. Left drum intact. Right drum ruptured. Small haemorrhage in middle ear. Ossicles in place.

Brain normal.

Would probably have died.

Lower Rabbit - Alive.

No external injury.

Abdomen normal.

Thorax. Right lung. Numerous petechial haemorrhages, mostly in lower part of lower lobe and lateral tip of upper lobe. Left lung similar.

Ears. Both drums ruptured. No haemorrhage.

Would probably have recovered.

Loader's Seat

Upper Rabbit - Alive.

No external injury.

Abdomen normal.

Thorax. A few petechial haemorrhages in thymus. Right lung. Petechial haemorrhages in form of rib markings in upper and lower lobe, particularly in medial part of lower lobe. Left lung. Numerous petechial haemorrhages in lateral part of lower lobe and lower part of upper lobe. Other parts nearly normal.

Ears. Right drum ruptured. Left drum damaged in dissection.

Brain normal.

Should have survived.

Lower Rabbit - Alive.

Severe singeing from head to tail.

Abdomen normal.

Thorax. Right lung. Numerous petechial haemorrhages all over, becoming confluent in medial part of lower lobe. Left lung. Petechial haemorrhages in lower and medial parts of lower lobe. Few elsewhere.

Ears. Both drums ruptured. Haemorrhage in middle ears.

Brain. Substance normal. There was a small clot extending round base. Should have survived.

Gunlayer's Seat

Upper Rabbit - Alive.

No external injury.

Abdomen normal.

Thorax. Numerous petechial haemorrhages in thymus. Right lung. Confluent petechial haemorrhages all over both lobes. Left lung. A few scattered petechial haemorrhages in both lobes.

Ears. Both drums ruptured. Small haemorrhages in middle ear. Ossicles intact.

Would probably have died.

Lower Rabbit - Alive.

Slight singeing on right side.

Abdomen normal.

Thorax. Right lung. Confluent petechial haemorrhages all over. Left lung. A few scattered petechial haemorrhages.

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Ears. Both drums ruptured. Small haemorrhages in middle ears.  
Ossicles intact.

Would probably have survived.

ROUND 4

Two rabbits each in loader's seat, driver's seat and gunlayer's seat.

Results

Gunlayer's Seat

Upper Rabbit - Alive.

No external injury.

Abdomen normal.

Thorax. Right lung. Very faint rib markings and a few petechial haemorrhages in both lobes. Left lung normal.

Ears. Both drums ruptured. Small haemorrhage in left middle ear.

Would have survived.

Lower Rabbit - Alive

No external injury.

Abdomen normal.

Thorax. Both lungs congested. A few scattered petechial haemorrhages in both.

Ears. Drums not examined on account of chronic suppurative otitis media (C.S.O.M.). (Middle ear full of thick pus.)

Would have survived.

Driver's Seat

Upper Rabbit - Alive.

No external injury.

Abdomen normal.

Chest. Faint rib markings both lungs.

Ears. Drums not examined. C.S.O.M.

Would have survived.

Lower Rabbit - Alive.

No external injuries.

Abdomen normal.

Thorax. Lungs normal.

Ears. Both drums ruptured.

Would have survived.

Loader's Seat

Upper Rabbit - Alive.

Fur singed.

Abdomen normal.

Thorax. Lungs normal.

Ears. Both drums ruptured. Middle ears full of blood.

Would have survived.

Lower Rabbit - Alive.

Fur singed.

Abdomen normal.

Thorax. Right lung. Marked emphysema, congestion and a few small haemorrhages, in lower lobe. Left lung. Haemorrhage at lateral border of lower lobe.

Ears. Left - C.S.O.M. Right - drum disrupted. Haemorrhage covering ossicles, which were in normal position.

Would have survived.

ROUND 5

Two rabbits each in gunlayer's and driver's seats.

Three of the rabbits were apparently uninjured. These were kept alive overnight and killed and examined next morning. None of them appeared to show any symptoms up to the time they were killed.

The fourth, the lower one in the gunlayer's seat, had extensive singeing of the fur so that the skin was exposed on the right flank. This one was killed and examined immediately after the trial.

Results

Gunlayer's Seat

Upper Rabbit - Alive.  
No external injury.  
Abdomen normal.  
Thorax. Lungs normal.  
Ears. Both drums disrupted. Blood in middle ears. Ossicles in position.  
Survived.

Lower Rabbit - Alive.  
Extensive burning of fur so that skin was exposed on right flank.  
Abdomen normal.  
Thorax. Normal except for very faint rib markings on both lungs.  
Ears. Left drum ruptured. Right drum. Complete disruption of membrane. Malleus displaced. Moderate haemorrhage.  
Should have survived.

Driver's Seat

Upper Rabbit - Alive.  
No external injury.  
Abdomen normal.  
Thorax. Lungs normal.  
Ears. Bilateral C.S.O.M.  
Survived.  
Lower Rabbit - Alive.  
No external injury.  
Abdomen normal.  
Thorax. Right lung normal. Left lung. Small area of collapse at top of upper lobe.  
Ears. Both drums ruptured. Marked haemorrhage in left middle ear.  
Survived.

ROUND 6

Two rabbits each in gunlayer's and driver's seats, one in commander's seat.

Results

Gunlayer's Seat

Upper Rabbit - Alive  
No external injuries.  
Abdomen normal.  
Thorax. Scattered petechial haemorrhages in both lungs, mostly in lower lobes.  
Ears. Bilateral C.S.O.M.  
Would have survived.  
Lower Rabbit - Alive.  
No external injuries.  
Abdomen normal.  
Thorax. Faint rib markings on both lungs and a few scattered petechial haemorrhages on left.  
Ears. Bilateral C.S.O.M.  
Would have survived.

Driver's Seat

Upper Rabbit - Alive.  
No external injury. Breathing was laboured and face and ears were cyanosed.

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Abdomen normal.

Thorax. Oedema and emphysema of both lungs. Large areas of collapse on postero-lateral borders of both lungs.

Trachea full of froth.

Ears. Bilateral C.S.O.M.

Although, to all appearances, the blast damage was only moderate, this animal would probably have died of oedema of lungs.

Lower Rabbit - Alive

No external injury.

Abdomen normal.

Thorax. Right lung normal. Left lung, very faint rib markings and a few petechial haemorrhages.

Ears. Both drums ruptured and blood in middle ears.

Would have survived.

Commander's Seat - One rabbit only.

Cage - At least 10 perforations up to 2 cm. long. 20 to 30 dents.

Rabbit, upper part of cage. Dead.

External injuries. Severe singeing all over body.

Several wounds:-

1. Lower part of ramus of right mandible, about 2 cm. diameter.

Fragment was not found but had penetrated some distance, causing comminuted fractures of mandible, maxilla and palate.

2. Near tip of last right rib, fracturing rib, penetrating diaphragm and rupturing right lobe of liver.

3. 2 cm. behind 2, penetrating abdomen and rupturing caecum.

4. Middle of right thigh 1 cm. long, penetrating into pelvis and causing comminuted fractures of right ilium, and right femur.

Massive haematoma in superficial fascia of neck. Several bruises of thoracic and abdominal walls.

Abdomen. Contained a quantity of semi-solid faecal material from a rupture of caecum 2 cm. long below the right lobe of the liver. Liver ruptured in two places:-

1. Lateral part of right lobe 2 cm. long corresponding to a perforation of diaphragm.

2. Upper part of left lobe 5 m.m. long corresponding to a bruise of chest wall. No perforation.

Thorax. Many small haemorrhages in both lungs including one 1.5 cm. long in medial part of left lower lobe. Small laceration of right middle lobe.

Ears. Right drum. Gross injury by splinter. Left drum ruptured and extensive haemorrhage in middle ear.

Cause of death - Multiple injuries.

There was only moderate blast damage.

SUMMARY

31 rabbits were exposed in various positions during 5 trials.

5 were killed. 26 survived the trial.

Of the 5 killed, all died of splinter wounds. None of the deaths was due to blast injuries.

Burn damage was absent in 19, slight in 4, moderate in 3, severe in 5.

Lung blast injury in the 26 survivors was absent in 5, slight in 12, moderate in 6, severe in 3.

29 ears were examined. 28 of the drums were ruptured, 1 was intact.

In the 4 brains examined there was no damage to the brain substance but one of them had a small haemorrhage inside the skull, probably due to injury to a meningeal vessel. It is not possible to draw any conclusions from this.

COMMENTS

If the tank had had a human crew it is reasonable to assume that any man within the splinter cone would have been killed.

Otherwise, the rabbit results give us no reason to suppose that there would have been any incapacitation. True, three of the 26 surviving rabbits had severe blast damage to the lungs and a fourth would probably have died though the damage was only moderate, but it is fairly certain that if larger animals had been the victims the lung damage would have been less severe.

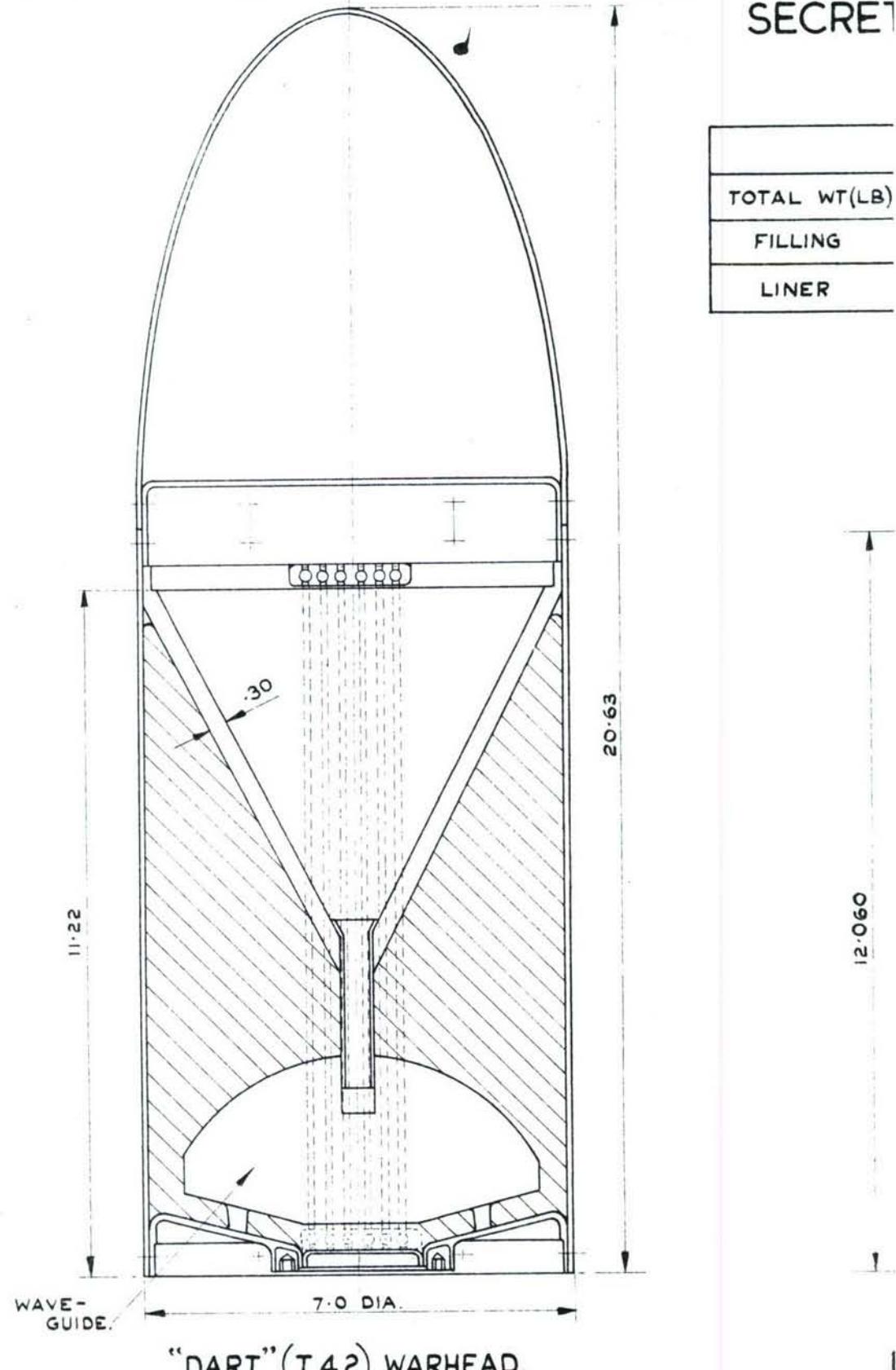
Ruptured ear drums would have been very common. The ear drum of a rabbit is smaller but it is also thinner than a man's and it is likely that the pressure needed to rupture it is not very different. This pressure for a rabbit is probably less than 15 lb./sq. in. and it may be a good deal less in a closed space.

SECRET DISCREET

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3. Roberts, L. R. and Mann, W. E. 1943 U.S.A., A.M.R.L. Fort Knox, Kentucky. First partial report on project 7 - 1.
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"DART" (T42) WARHEAD.

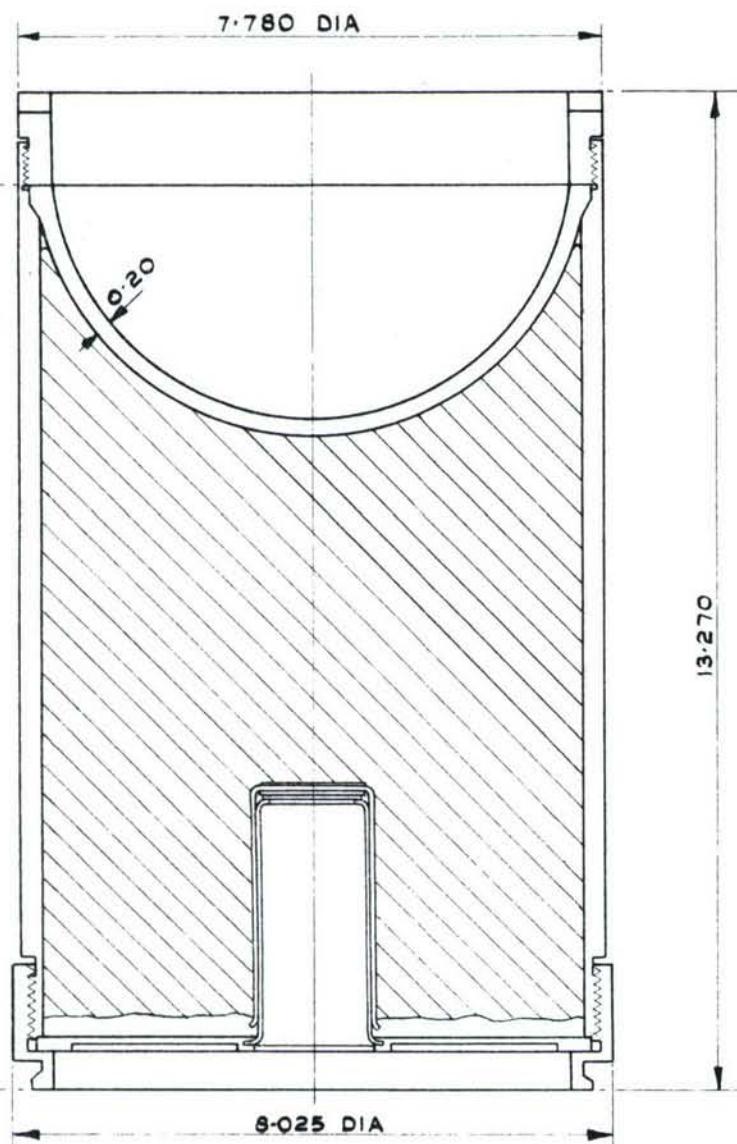
TOTAL WT(LB)
FILLING
LINER

SECTIONS OF WARHEADS.

FIGHTING VEHICLES RESEARCH & DEVELOPMENT

RET.

	"DART"	"MALKARA"
T(LB)	23 (WITH BALLISTIC CAP)	52.2 (WITHOUT BALLISTIC CAP)
	15 (COMP. "B")	21.3
	2.7 (ALUMINIUM CONE)	4.9 (COPPER HEMISPHERE)



EXPERIMENTAL "MALKARA" WARHEAD.

DS.

MENT ESTABLISHMENT.

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FIG. N° 1.

2



FIGURE 2. CONQUEROR SHOWING SPACED ARMOUR PROTECTION



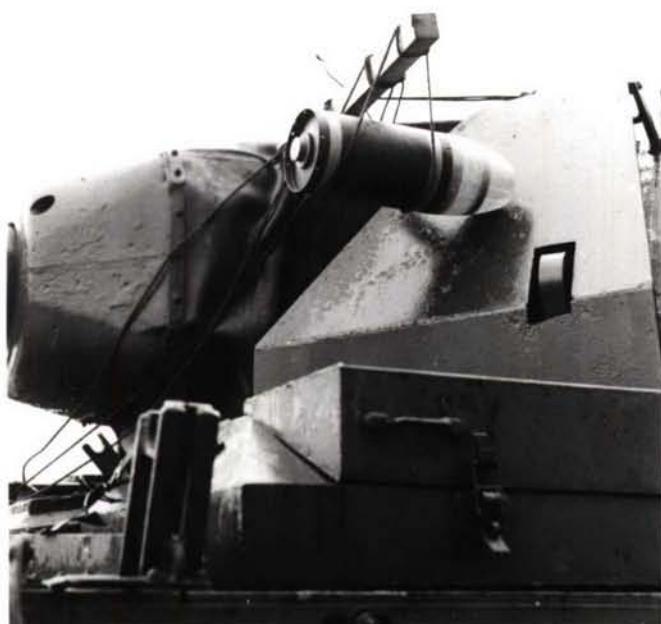
Figure 3 Radiograph of Dart Warhead

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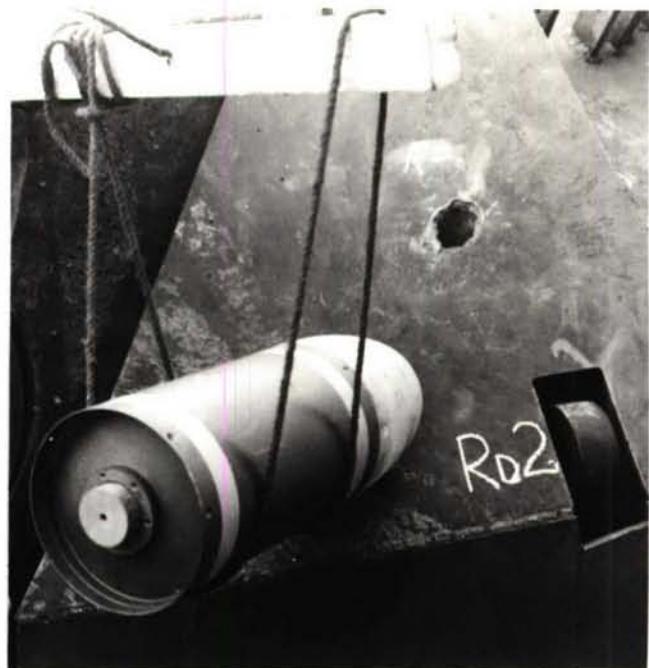


Figure 4 Radiograph of Dart Warhead  
Area X-X shows discontinuity  
Area Y-Y shows porosity

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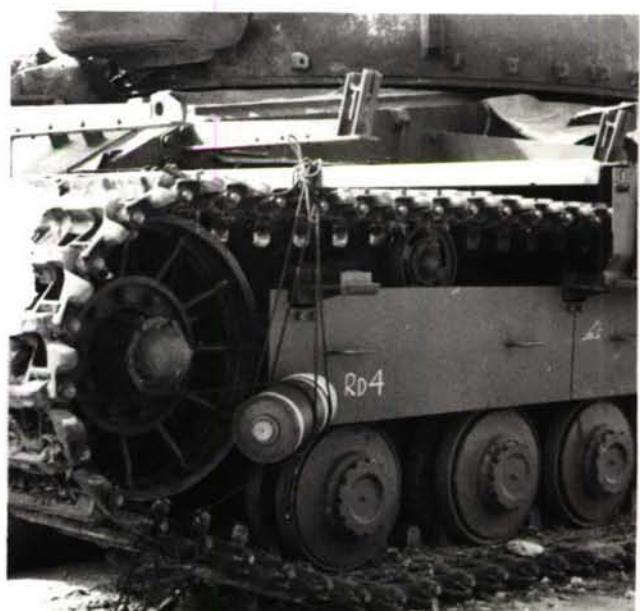
ROUND 1



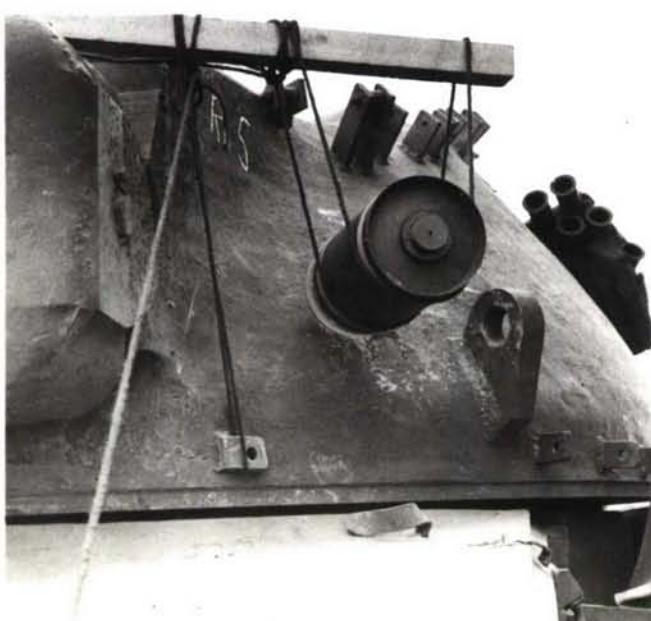
ROUND 2 (SPACED ARMOUR AS FOR ROUND 1)



ROUND 3



ROUND 4



ROUND 5



ROUND 6 (MALKARA)

FIGURE 5. POSITIONS OF WARHEADS

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GENERAL VIEW



BURRING OF MANTLET BY MALKARA ROUND



INTERIOR DAMAGE TO ARMOUR BY DART.  
ROUNDS 1 AND 2

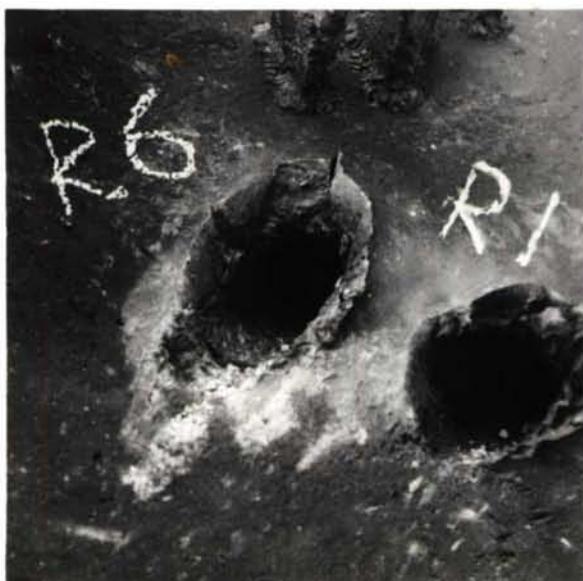
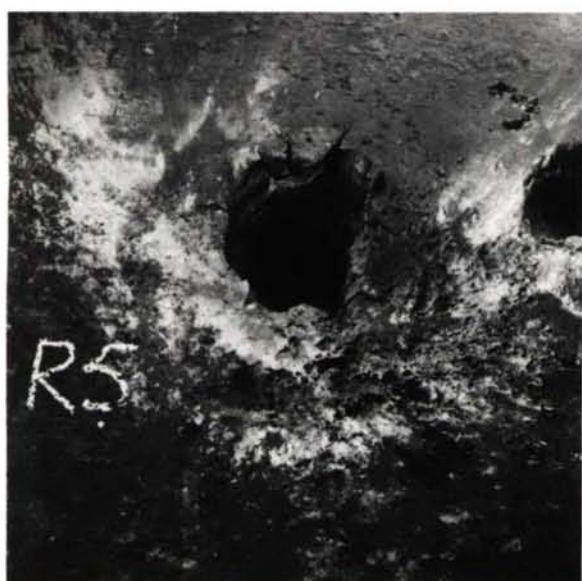
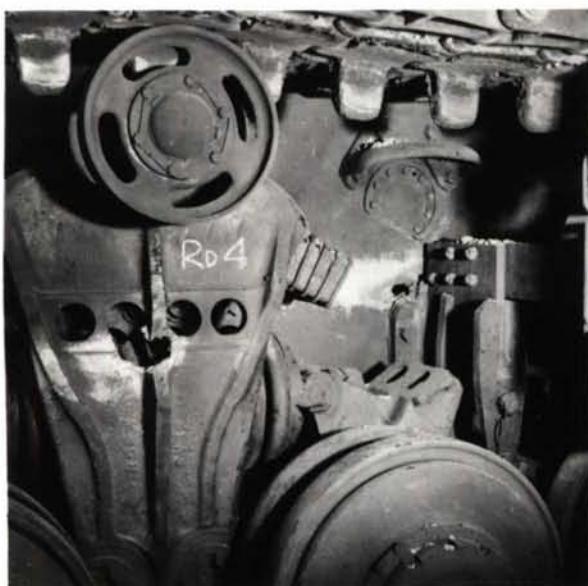


BACK DAMAGE DART. ROUND 3.

FIGURE 6. TYPICAL JET HOLES AND DAMAGE

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OUTSIDE

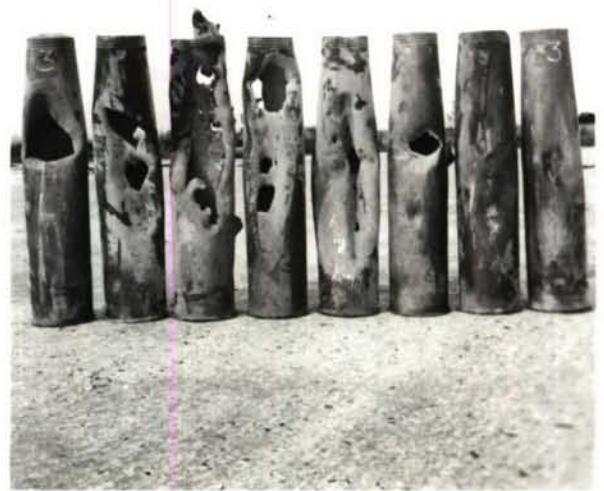
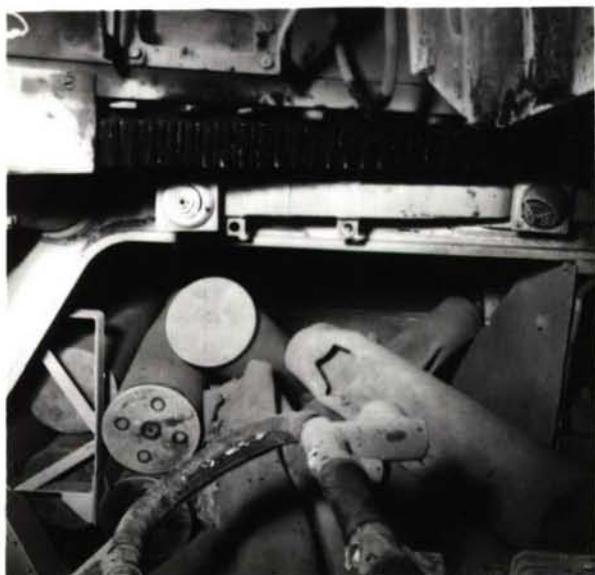


INSIDE

FIGURE 7. TYPICAL JET HOLES

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ROUND 3 (HULL NOSE)



ROUND 5 (TURRET FRONT)

FIGURE 8. TYPICAL CARTRIDGE CASE DAMAGE

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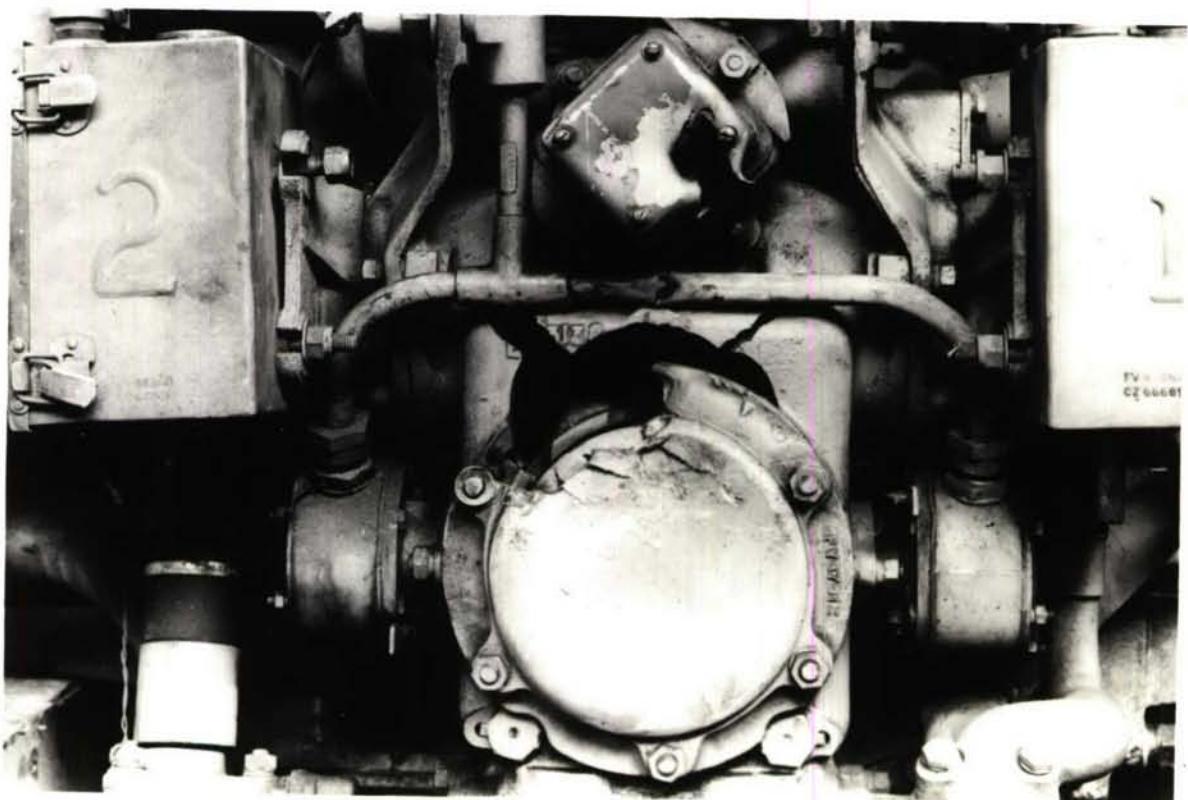
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TRaverse INDICATOR CONTROL DAMAGED BY ROUND 6

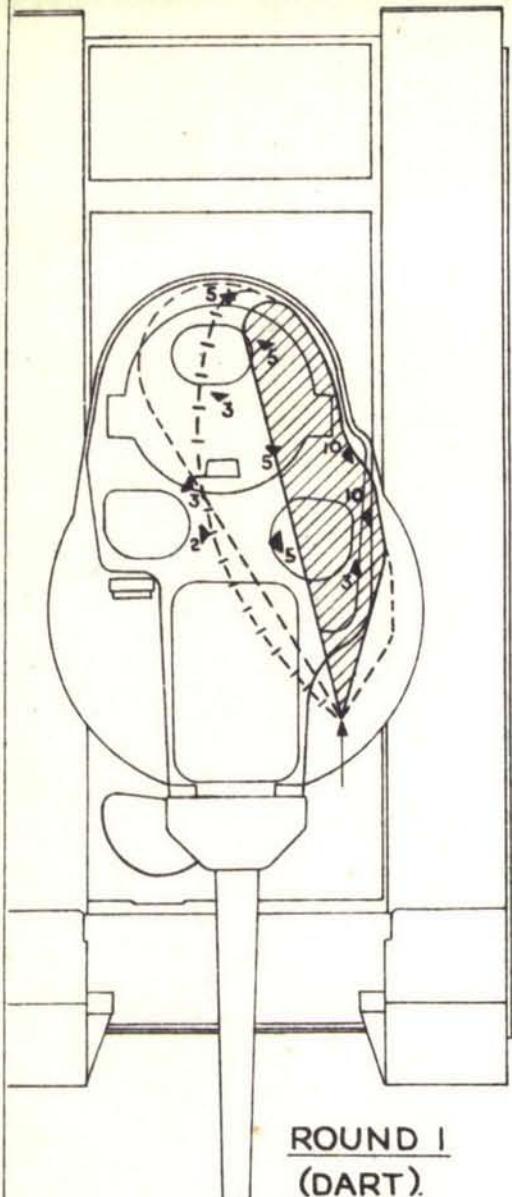


FRONT END OF ENGINE DAMAGED BY ROUND 6

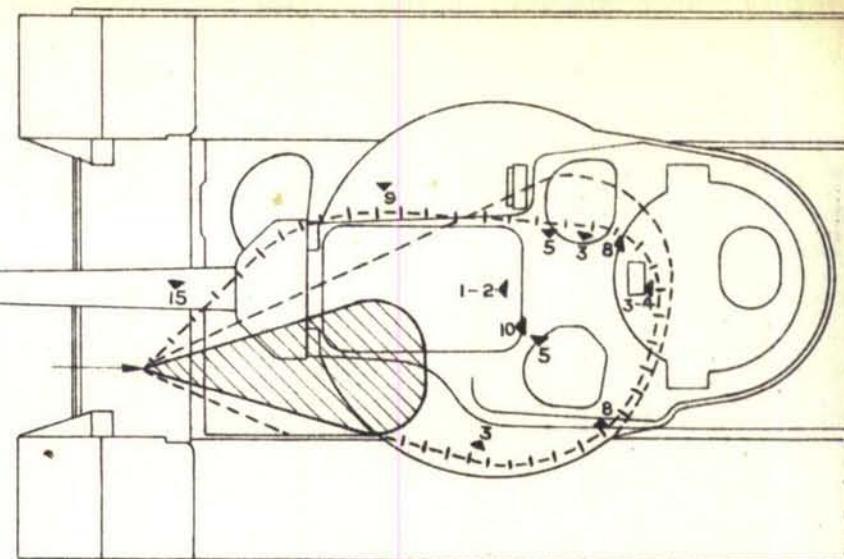
FIGURE 9. TYPICAL INTERNAL DAMAGE

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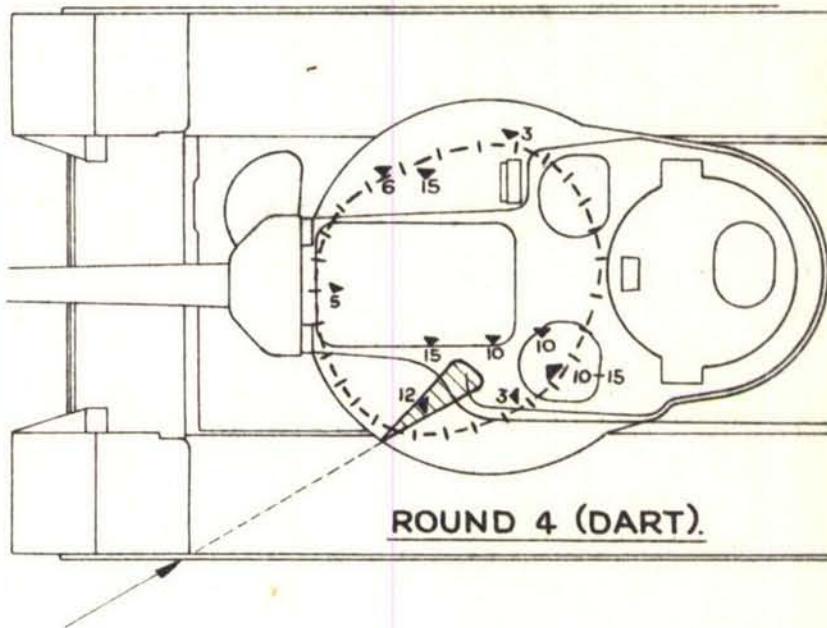
REPORT NO: T.R.2/2



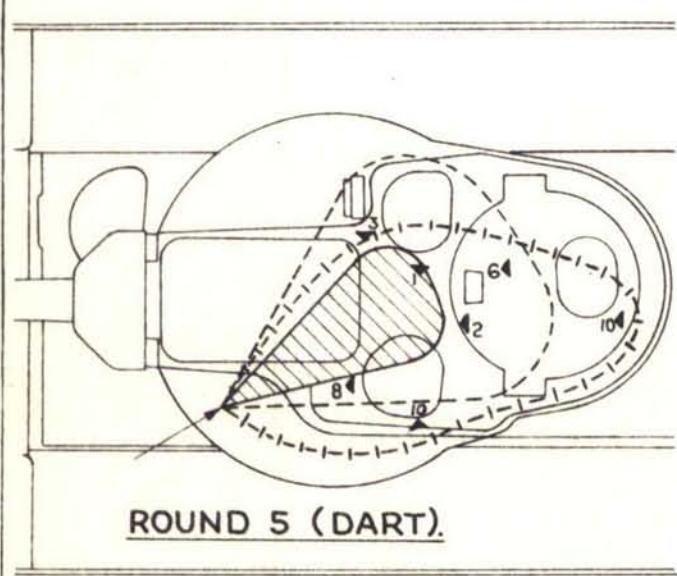
ROUND I  
**(DART).**



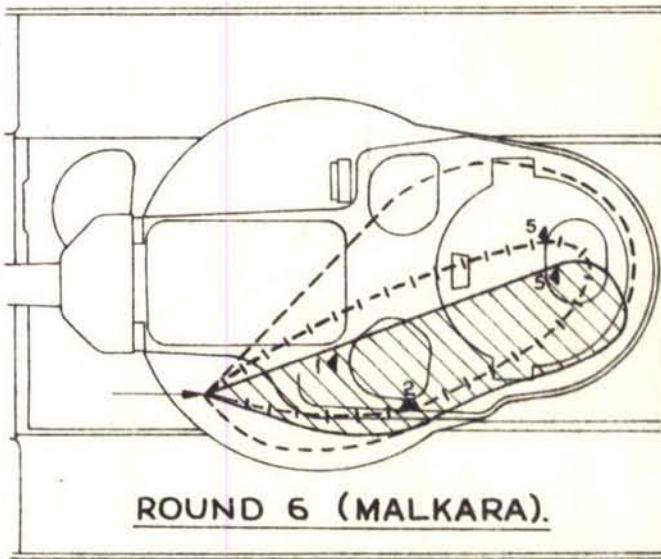
### **ROUND 3 (DART).**



#### ROUND 4 (DART).

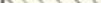


ROUND 5 (DART).



## ROUND 6 (MALKARA).

A horizontal number line starting at 0 and ending at 10. There are 10 major tick marks labeled 0, 5, and 10. Between each major tick mark, there are 9 minor tick marks, creating 10 equal intervals of length 1 unit each.

 ESTIMATED LETHAL ZONE.

----- LIMIT OF FRAGMENT INJURIES.

- - - - - LIMIT OF THERMAL INJURIES.

### **3 ► HEAT SENSITIVE INDICATOR READINGS.**

#### ZONES OF INJURY FROM FRAGMENTS & BURNING.

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